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U.S. Department of Commerce
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Final Report

LEVEL III

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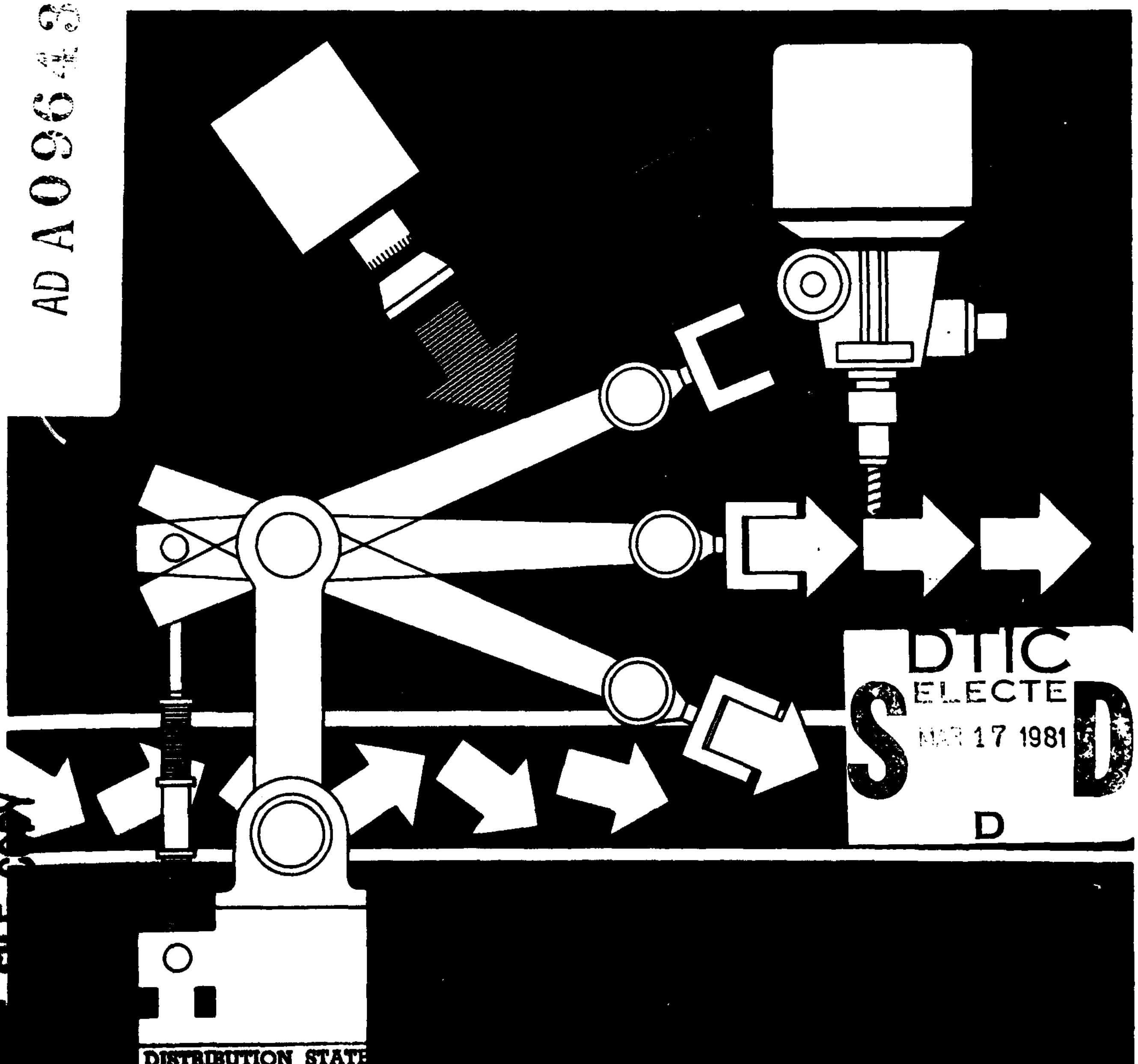
Guidelines for Exchangeable APT Data Packages

NBSIR 80-2073.1

Bradford M. Smith

June 1980



Automation Technology Program

NBSIR-80-2073.1

GUIDELINES FOR EXCHANGEABLE APT DATA PACKAGES

Bradford M. Smith

Jun[redacted]80

Final Report

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Jordan J. Baruch, *Assistant Secretary for Productivity, Technology, and Innovation*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Users of numerical control (NC) machines could save considerable time and money if it were possible to quickly and easily exchange part program data among different NC machines. Historically the Air Force Logistics Command (AFLC) has used a program called APT to help prepare control data for its large inventory of NC equipment. Software postprocessors link the APT system with each individual machine tool. However, because of an early lack of standardization in the APT language used to control machining functions, a programmer must write slightly different APT part programs to produce the same part on different machine tools.

The National Bureau of Standards working in cooperation with the five Air Logistics Centers (ALC) has developed and tested a method of APT programming and postprocessor design which permits this exchange at the APT source language level for milling-drilling type machine tools. The technique involves no changes to machine tools or controller hardware and no changes to the APT general processor other than simple vocabulary additions. All other modifications are localized in the postprocessors.

Sponsored by the Producibility, Reliability, Attainability and Maintenance Office at Sacramento ALC under Military Interdepartmental Purchase Request FD 2040 78 60013, the project developed a comprehensive plan for modifying AFLC software. The Project Manager at Sacramento was Mr. Cleon Binyon, and software modifications at Ogden were under the direction of Mr. Malcolm Allen.

The approach was successfully demonstrated in production at Sacramento by processing a single APT data package on three different milling-drilling type machine tools.

Kearney and Trecker three spindle profiler - 3 axis
Giddings and Lewis vertical machining center - 3 axis
Pratt and Whitney horizontal machining center - 4 axis

The APT part program was processed for each machine by changing only the MACHIN selection statement and the part ORIGIN statement. This exchangeability of part manufacturing data was made possible by modifying the postprocessor software to process each APT statement in the same manner for all machine tools. Thus the original intent of the part programmer was satisfied on all three machine tools regardless of whether the function was performed automatically by the machine or was simulated by other means such as by the postprocessor or by requests to the machine operator.

Project results are contained in four documents:

- Guidelines for Exchangeable APT Data Packages
- AFLC APT Part Programmer's Manual
- AFLC APT Postprocessor Specifications
- AFLC Postprocessor Software Guide

The first report details the approach taken and the benefits measured. The Part Programmer's Manual documents the functions to be performed at the machine tool for each APT language statement. This one manual will serve the needs of all milling-drilling type machine tools in AFLC whereas before, every machine required its own different programming manual. The Postprocessor Specifications are to be used in the procurement of new postprocessors along with future machine tools. Initially, it is expected that the requested software will result in additional expense until vendors recognize the logic of the approach taken. Finally, the Software Guide was developed to assist Ogden ALC personnel in modifying some 30 existing postprocessors to implement the approach across all of AFLC's production facilities. This figure includes 21 existing postprocessors plus 9 anticipated near term procurements.

A Steering Group of numerical control manufacturing experts from each ALC provided guidance and direction for the project to insure that results would reflect a generic need and not just that of Sacramento. This group has developed a prioritized plan for full implementation across 31 machine tools at the five AFLC facilities. Furthermore, the group has projected an 23 % increase in numerical control manufacturing efficiency upon complete implementation. Elements of these savings are:

More Efficient Programming	- 8 %
Less Reprogramming of Workload	- 6 %
Reduced Computer Charges	- 5 %
Simplified Training	- 2 %
Better Shop Scheduling	- 2 %

BACKGROUND

The typical user of NC machine tools has high praise for the increased productivity and the better control over the manufacturing process that NC has brought him. But a careful look at shop operations will often identify problems that are all too familiar to veterans in this field; idle machines waiting for tapes, work stacked up on machines which are down for maintenance, and part programmers wrestling with the details of reprogramming some jobs for other machines. These nonproductive operations highlight several technical problems which must be solved before users can achieve maximum benefits from their NC equipment.

One problem very basic to NC is the lack of interchangeability of part manufacturing data among different machines. Productive utilization of a group of machine tools is enhanced by the ability to interchange jobs among the machines, and to be able to do this with minimum costs and time delays. For years, NC users have needed to be able to quickly and easily exchange part manufacturing data among their NC machines. But the proliferation of different controls, optional features and tape coding schemes have precluded much hope of this unless a shop was able to standardize on a single NC controller or could afford to retrofit all their machines to the newer CNC controls.

Recognizing this problem, the National Bureau of Standards (NBS) proposed to the Air Force Logistics Command (AFLC) a joint effort to develop, test and demonstrate a method which would allow part manufacturing data to be developed in a high level language and in a common format for all milling-drilling type NC machines. A Steering Group of ALC experts, listed in Appendix 1, was established to guide this effort. The project involved the definition of a common format by the Steering Group and NBS, the modification of production software by NBS and Ogden ALC, and the machining demonstration at Sacramento ALC. A detailed schedule for the project is given in Appendix 2.

PROBLEM

While sharing tapes among NC machines has seldom been possible, the sharing of part data may be made practical through the use of higher level programming languages. APT is one of these higher level languages and is used by many NC shops.

One objective in the development of the APT language processor was to lessen the computational burden on the part programmer. This has been accomplished successfully. However, another design intent was to be able to postprocess the same part program for any machine simply by changing the MACHIN statement. Unfortunately, present APT systems fall short of doing this because various machine postprocessors require slight differences in their input language. These language inconsistencies force a part programmer to choose which machine will be used before he starts to program. Thus, present APT part programs cannot be reused without modification for any machine other than the one originally chosen for machining the part.

One problem involves language syntax. A programmer is forced to use slightly different APT statements to achieve the same result on different machine tools. For instance, the statements below invoke the same spindle speed and tapping cycle on two different machines. Yet if they are interchanged, error diagnostics are produced instead of parts.

```
SPINDL/1000,CLW,HIGH              CYCLE/TAP,z,f,IPM

SPINDL/RANGE,HIGH,RPM,1000        CYCLE/TAP,RAPTO,n,FEDTO,z,IPM,f
```

A second problem which causes trouble in exchanging APT data involves part programming statements which call for features not available on the other machine tool - features such as an automatic tool changer. These part programming commands, when postprocessed for the other machine, will either produce error diagnostics or worse yet, will be ignored without comment, leaving the programmer to believe that the tape is good. Some of the commands which fall into this category are:

```
LOAD/TOOL          ROTATE/TABLE

AIR/ON             CUTCOM/ON
```

A third problem involves semantics. There are some language statements which have different meanings to different machines. For instance, the statement GOHOME does not cause the same sequence of actions on all machines. These various inconsistencies in the APT postprocessor language and in the way that language is interpreted by postprocessors complicate the task of running a part program on any machine other than the one originally selected for the job. However, one can see that the problems are not insurmountable.

APT LANGUAGE SELECTION

A major requirement for achieving the objective of rapid and simple exchange of APT part programs among different NC machines is a common language for the machine dependent APT statements. This choice of language was heavily influenced by the American National Standards Institute (ANSI) X 3.37 - 1980, the latest U.S. Standard for the APT Language. This revision addresses much of the postprocessor language needed for the project and was adopted as a starting point. Additional vocabulary was developed for those areas of the ANSI APT where no language had yet been specified. The exact choice of vocabulary was discussed with the lead part programmers throughout the Air Logistics Centers and with other personnel in the Army, Navy, Air Force, other government activities, and several private industrial firms. The exact choice of language is documented in the AFLC APT Part Programmer's Manual.

But having a language set is only part of the solution. It specifies only the input to the postprocessor. The second requirement for part program portability is that all postprocessors execute each APT command in the same way. One must determine the desired functional output of each language statement - the sequence of motions at the machine tool. Our project analyzed 32 postprocessor vocabulary statements shown in Table 1 to define the desired actions. These are also documented in the Part Programmer's Manual. Normally, there is a different part programmer's manual for each NC machine tool. However, using the methodology developed by this project, only one such manual will be required for all NC machines of the milling-drilling type.

Table 1 - APT Postprocessor Major Words

AIR	INSERT	RETRCT
BREAK	LEADER	REWIND
CLAMP	LINTOL	ROTATE
CLRSRF	LOAD	SELECT
COOLNT	MCHTOL	SEQNO
CUTCOM	OPSKIP	SET
CYCLE	OPSTOP	SPINDL
DELAY	ORIGIN	STOP
END	PIVOTZ	TMARK
FEDRAT	PPRINT	TRANS
GOHOME	RAPID	

Given the input language and the desired functional output we evolved a philosophy for modifying and/or constructing postprocessors such that part programs can be interchanged. It has four major elements:

All postprocessors must accept the same statement syntax.

A postprocessor must recognize all statements and flag those which cannot be processed.

The meaning of each APT statement must be the same for all postprocessors.

The postprocessor must always ensure that the desired function is accomplished, either directly or by simulation.

A primary guideline of this philosophy is to satisfy the intent of the part programmer at all times. Where this intent cannot be met automatically by the chosen controller and machine tool, the postprocessor must simulate the action desired. Sometimes this requires the assistance of the machine tool operator. A few examples will serve to illustrate.

Task	Statement
Load cutting tool 21 into spindle	LOAD/TOOL, 21, LENGTH, 3.75

Ordinarily this statement is used to control an automatic tool changer in a sequence that is quite familiar. With the new approach to exchanging part programs, this same LOAD/TOOL statement is used whenever the programmer desires to change a tool regardless of whether the machine tool is equipped with a tool changer or not. When the statement is processed for a machine without tool change capability, the following actions are generated; move the machine to the manual tool change position, stop the spindle, lock the spindle if necessary, and issue a comment to the operator with instructions to load the tool. In this way the desires of the part programmer can be met by all NC machines.

Task	Statement
Provide a dwell of four seconds	DELAY/4

This statement usually results in tape codes that cause the NC controller to halt feedrate motion for the preset time. In cases where this controller feature is not present, it may be possible for the postprocessor to calculate and output a number of leader characters to accomplish the desired dwell time. Otherwise a warning diagnostic would normally be issued to advise the part programmer that the intent cannot be satisfied on the selected macnine and controller.

SOFTWARE MODIFICATION

The key to implementing this strategy is the modification of APT postprocessor software to process each APT statement in the same manner for all machine tools. To demonstrate this approach at Sacramento ALC, three postprocessors were modified by Ogden for the following machines:

Kearney and Trecker three spindle profiler	- 3 axis
Giddings and Lewis vertical machining center	- 3 axis
Pratt and Whitney horizontal machining center	- 4 axis

These software changes are documented in a companion report, the AFLC Postprocessor Software Guide. It must be recognized that a great diversity exists among postprocessors. Each generally has been developed by different sources and incorporates different software processing techniques. AFLC currently has 39 postprocessors, 28 of which represent substantially different codes. The normal procedure for modifying any one of these is for a computer programmer to first learn the detailed operation and structure before devising specialized code changes to implement the new capability. While this approach works, the trouble for AFLC is that changing the second or third postprocessor is just as much work as the first. The Software Guide details another approach which although far from optimum does alleviate some of the repetetive work and appears to be a more economical method for modifying those postprocessors needed by AFLC.

The process is accomplished in a stepwise manner with tests performed after each modification so that the production integrity of the postprocessor is maintained. A total of ten test part programs were developed for this purpose. Neither the Guide nor this project is intended to imply a standardization of the FORTRAN code in all postprocessors. Quite the opposite, only the input data to a postprocessor has been standardized. The CL file represents the standardized coding, format and functional intent of the original APT part program. Thus, the syntax and semantics of the APT postprocessor language plus the CL file are the only things standardized. This software guide serves only as a reference to document the modifications which were made to three in-house postprocessors. Other implementors of this concept will probably choose an entirely different modification scheme in their FORTRAN code. How they do it is immaterial, for the only important point is that the postprocessor - controller - machine combination function according to the specifications in the AFLC Part Programmer's Manual. If this is done consistently and is done well, users will have the portability they desire and management will see more productivity from their NC investment.

BENEFITS

Full implementation of this methodology will produce savings in terms of labor content, leadtime, and cost of NC manufacturing both on new work as well as on maintenance and repair work. At a meeting of the AFLC Steering Group in Sacramento these savings were calculated to be a 23 % increase in numerical control manufacturing productivity. Elements of these savings are:

MORE EFFICIENT PROGRAMMING - The part programmer's task is simplified since there is no need to remember the idiocyncracies of each machine tool's APT language. There will be fewer errors in coding, leading to fewer computer runs for each part. There will be less time spent referring to part programming manuals. The Steering Group estimated that labor savings are 8 % of annual workload.

LESS REPROGRAMMING OF WORKLOAD - Since a part program can be processed quickly and easily for any available machine tool, costly reprogramming of parts is eliminated. Table 2 shows for the five ALC's in calendar 1979 that an average of 6 % of a part programmer's time was spent in reprogramming parts because the machine for which the program was originally written was not available to do the job.

REDUCED COMPUTER CHARGES - Indirect savings are expected in areas such as cost of computer time and materials since fewer computer runs are anticipated for each completed job. Overhead costs such as these are difficult to quantize but data from Sacramento indicates an average of seven computer runs per job. Conservatively, one run per job could be saved via this approach leading to a 5 % annual savings.

SIMPLIFIED TRAINING - New personnel can be more completely trained in a classroom environment rather than on-the-job resulting in a 2 % savings.

BETTER SHOP SCHEDULING - Workload can be more efficiently scheduled, and priority work can be accomplished without major disruption of ongoing projects. The savings from having to tear down machines in the middle of a job is estimated by Sacramento at 2 %.

Table 2 - Benefits from Less Reprogramming

Total Hours per Man-Year	2096	
Less leave, holidays	337	
Less non programming tasks	668	
Training, tooling		
Drafting, designing		
	*********	
Net Programming Time Per Man-Year	1091	hours

Air Logistics Center	Hourly Reprogramming Workload	Average Number of Programmers	Total Hours of Workload	Per Cent Reprogramming
Ogden	368	4	4364	8.4
Oklahoma City	452	8	8728	5.2
San Antonio	294	7	7637	3.8
Warner Robins	566	6.5	7091	8.0
Sacramento	281	6	6546	4.3
Average % Reprogramming				6.0

IMPLEMENTATION PRIORITIES

This project has developed the basic framework for an enhanced NC software system that holds significant benefits for both users and management. The Steering Group has recommended full implementation of the concept across AFLC. A total of 31 machines are involved as shown below. The machines are listed in priority order for each of the five shops and do not include those slated for near term replacement.

SAN ANTONIO

1	Sundstrand Series 80	new
2	Sundstrand OM 3	BXOM35
3	K+T Moduline	CONCRD,044012
4	B+S Machining Center	CINCY,2
5	Hydrotel	BENDIX,2566

OKLAHOMA CITY

1	Sundstrand OM 1	BCSPOS,12
2	Sundstrand OM 1	BCSPOS,20
3	XLO Vicker	XLONCS,108
4	Burgmaster VTC	BURG,160
5	Hillyer AB	AB4500,10
6	MOOG	MOOG,2
7	Cincinnati	CIMTRL,22

7 more machines anticipated

WARNER ROBINS

1	CIMX	CINAC9,076
2	CIMX	new
3	K+T Moduline	SUNTRN,103005
4	Hydrotel	CINAC7,083

OGDEN

1		NCVPTH,2
2		CINAC1,125100

SACRAMENTO

1	Brown & Sharpe	BROWNS,1
2	Gorton	BR3100
3	G & L Die Mill	DIMILL,1
4	Pratt & Whitney Cub	AB3300,18
5	Cincy Hydrotel	CINAC6,004
6	XLO 4 axis	XLOAB5

CONCLUSION

Portability of APT part program data among functionally similar NC machine tools is a prime concern for users of this automation equipment. Existing standards for the postprocessor language do much toward simplifying the exchange of data but are not adequate to ensure total portability. The guidelines developed by this project enable portability through a consistent specification of machining functions that result from the use of each APT language statement. Whether these functions are carried out by the post-processor, the NC controller, the machine tool or the operator is immaterial. The essential point is that they be carried out consistently for all machines. The postprocessor - controller - machine tool - operator combination must at all times satisfy the intent of the part programmer. In this way exchangeability of APT data packages becomes possible.

This project has addressed only the milling and drilling type machine tools, but the approach and benefits are clear for subsequent application to lathe operations. Furthermore, the approach is equally applicable to systems where the postprocessor is resident on the mainframe computer or to systems where it is imbedded in the NC control unit. The technique has shown significant benefits in actual production. Implementation involves no changes to machine tools or controller hardware and no changes to the APT general processor other than simple vocabulary additions. The key lies in the postprocessor software. It is the mechanism which must compensate for the many differences in electronic controller features and machine tool options.

APPENDIX 1

STEERING GROUP

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APPENDIX 2

PROJECT SCHEDULE

Headquarters Air Force Logistics Command (AFLC) Code MAXF will create a steering group to meet with the National Bureau of Standards at Ogden Air Logistics Center (ALC) to identify project personnel and the NC production equipment to be involved. (April 78)

Sacramento ALC Code MA will be Office of Primary Responsibility (OPR) will furnish programming manuals on the NC equipment selected. (May 78)

A committee, as designated by the steering group, will analyze the present AFLC software and the APT Postprocessor Language currently in use. (June 78)

The combined committee will investigate the new ANSI standard for applicability and will select final language features to be used. (June 78)

NBS will document the language chosen in a Part Programmer's Manual. (July 78)

NBS will specify the functional machine response for each language command and will differentiate those actions which can be performed automatically from those which must be simulated by the postprocessor. (November 78)

NBS will furnish to Ogden ACD the written documentation for implementation of this approach on the NC machines selected. (November 79)

Ogden Code ACD will modify postprocessors for the selected machines. (December 79)

Sacramento ALC will host an end of project demonstration running at least three test programs, using the materials developed. (January 80)

NBS will furnish additional written documentation to enable computer programmers to implement the standard on all machine centers in the Air Logistics Command. (February 80)

NBS will furnish Headquarters AFLC Code MAXF written quarterly progress reports and a final written report on all products developed in this study. (February 80)

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Mr. Bradford M. Smith

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McClellan Air Force Base
California 95652

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15. SUPPLEMENTARY NOTES Three other reports complete the documentation on this project: APT Part Programmers Manual, APT Postprocessor Specifications, and The Postprocessor Software Guide

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A method of APT programming and postprocessor design is described which permits more efficient data preparation for numerical control (NC) machine tools and then allows this data to be quickly and easily exchanged among different NC machines. A rigorous specification is made of the APT postprocessor language based upon new ANSI standards for APT and is coupled with a comprehensive definition of the machining functions which should result from the use of each APT language statement. Individual postprocessors are modified to process each statement in the same manner. Thus, the original intent of the part programmer is always satisfied. A 23% increase in NC manufacturing efficiency is projected. The approach is demonstrated in production by processing a single APT data package on three different milling-drilling type machine tools. This Final Report details the approach taken and the benefits measured.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

APT; Automation; Computer aided manufacturing; NC machining; NC programming; Numerical Control; Part programming

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